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Harnessing the Brute: The Development of Propulsion Controlled Aircraft at NASA Dryden

1 Introduction

PCA, Performance Control Aircraft, is a backup flight control system for use when an airplane has lost all its hydraulics and normal flight controls. PCA is an autopilot system which modulates the thrust of the engines to provide lateral and longitudinal direction and enables the pilots to land the airplane. NASA Dryden has developed this technology in flight, ground simulator, and analytic studies which started as early as 1989. NASA Dryden has combined efforts with NASA Ames, McDonnell Aerospace St. Louis, Douglas Aircraft Long Beach, Honeywell, Pratt & Whitney, the US Air Force, and the US Navy to develop PCA to the point where it is feasible to bring a commercial airliner not just to a survivable crash landing but to a normal landing.

The purpose of my project was to develop a history of an invention which evolved by group problem-solving. My focus was not on validations arrived at -- these are already documented in technical reports -- but on the inventive process. I have previously published work about individual inventors and their processes, one of these studies concerning Philo Farnsworth's Image Dissector, the crucial invention for all-electronic television [1]. The Image Dissector history concerns the classic lone inventor scenario. But PCA is the history of often reconfigured teams developing an invention in our modern environment governed by complex commercial and regulatory units, a story of, as one engineer put it, "how you push a good idea through the system."

2 History of Inspiration

At 30,000 feet altitude flying to St. Louis on a business trip, Bill Burcham, then Chief Propulsion Engineer at NASA Dryden, first began to think about PCA. The idea started as a sketch on the back of a TWA cocktail napkin. It was September, 1989, and he had just laid aside a copy of an industry magazine describing a commercial airline disaster.

On July 19, 1989, United Flight 232 had experienced disaster during a routine cruise over Iowa farmlands. The rear engine of the DC-10 had blown out, destroying the hydraulic system. The hydraulics operate all the controls which a pilot uses to control flight. The airplane had three hydraulic systems, two of them independent backups, but the shrapnel from the explosion took out all three. Suddenly, the control stick was dead in the pilot's hand.

The crew made the discovery that by nudging the throttles to the two remaining engines, they could herd the airplane across the skies. Flight controllers directed the airplane to the Sioux Gateway Airport at Sioux City, where emergency preparations had already begun. At 1600

hours, the airliner made a partially successful landing on Runway 22, cartwheeled during touchdown, yet 184 of the 296 on board survived the crash and ensuing fire.

What more could I have done to help the pilots, wondered Burcham. He asked, could the raw power of the engine bring a crippled airplane down to a safe landing? He thought about the whole new generation of airplanes evolving with automated flight control computers and with computers that digitally ran the engines. Could the brute force of engine thrust be harnessed to control the airplane? Could the airplane's digital software operate the throttles with enough finesse to bring the airplane safely down? [2]

3 Concept

To think in terms of how to control an airplane but ignore all flight control surfaces was to return back to the century before the Wright Brothers -- even Orville and Wilbur from the beginning understood that control surfaces harnessed the power of flight. When all control surfaces are lost, there occur certain aerodynamic movements no pilot ever wants unleashed. The two most basic of these are the dutch roll oscillation and the phugoid oscillation.

All of us have experienced phugoids in airflight. They probably make an appearance as no more than slight nibbles in a smooth passage, arising so gradually that normally the pilot touches the stick and kills the oscillation without thinking about it. As long as control surfaces work, the phugoid remains a sleeping monster.

The phugoid is a pitching motion in which kinetic and potential energy (speed and altitude) are traded. The oscillation typically lasts about 60 seconds. As the airplane's nose pitches to the highest point, speed slows. As the nose drops back toward the middle of the cycle, speed increases. Then as the nose pitches down, speed slows. The experience resembles a sort of eerie slow motion roller-coaster ride. Its effect on landings can be fatal.

The dutch roll oscillation has more to with the lateral axis, and resembles a drunk's walk where the inebriate pauses with every step, tilts on one foot, and lurches in the other direction. The oscillation combines several factors including yaw, roll, dihedral effect, lift, and drag. During the complex mode, the airplane's nose rotates in a 3° lateral mode. Unfortunately, a 1° latitude exists for safe runway touchdowns.

To control these oscillations, the researchers started with manual control. The big lethargic engines took what seemed an eternity to respond. It was wait-and-see flying, a sort of dismaying process of anticipation. The pilot commanded, the pilot waited. To a nonpilot, the comparison would be driving and having to turn the steering wheel ten seconds in advance of any movement needed. A phugoid lasts about 60 seconds and the thrust input to damp it must be given more than 20 seconds before any perceptible cue to do so. Unfortunately in disaster, "Pilots will revert to natural instincts and natural flying instincts will kill you" [3].

The researchers' insight, which dated back to the sketch on the napkin, was that while a pilot would find it impossible to stop a phugoid with only 50-50 odds of even nudging the thrust in

the right half of the oscillation, if a computer could help, if it could 40 times per second receive responses from motion sensors and react to each with a tiny correcting nearly imperceptible nudge of the throttle, the airplane could be controlled.

4 History of Development

The idea of PCA was big. It was big in unexpected ways and so robust it kicked in sometimes more strongly than the engineers had ever predicted. Burcham was the first impetus behind the project, but PCA was much bigger than any one individual, and teams would form and reform, members dropping in and out, as their assignments required. At a center known for supersonics, this subsonic idea lumbered along with the speed of a transport. It survived, moving through an institution, through units and sub-units, a bit of a stealth project because it had no budget to be shot down, moving through "mature technology," moving through an engineer's off-time on Saturday afternoon, through carpool debates, reviews, and reconfigurations with other units and experts which would help it survive. My project concerns the teams and their members, Gordon Fullerton, the ex-astronaut who became project pilot; the other pilots, Dana Purifoy, John Miller, Ralph Luczak, and Walt Smith; Ken Szalei, NASA Dryden Director, who offered remote but crucial support; important control law work from Trindel Maine, John Burken, Joe Conley, Glen Gilyard, and Ed Wells; Honeywell's Jeff Kahler, the wizard who put PCA in the FCC; the pivotal project management of Drew Pappas; and important management from Jim Stewart, Joel Sitz, Bob Baron, Jim Urnes, and Russ Barber. Through their efforts, a series of historic flights have demonstrated the concept in actual flight landings on the F-15 and on the MD-11. Currently tests continue with the C-17 and B-747 to make this technology applicable to the realities of commercial airlight.

5 Conclusions

The success of PCA despite widespread skepticism and often zero funding suggests: **1.** A small team with highly skilled individuals may be more effective than putting larger groups with a lower median skill level on a project. **2.** Although budget is key, in certain stages it is not the most important key. **3.** A principle investigator who shares opportunities as broadly as possible enables the project to benefit often unexpectedly. **4.** It may help to leverage upward by reconfiguring with other units, centers, and institutions. There is an art to "surfing" an idea through the industry environment.

6 References

- [1] Tom Tucker, *Brainstorm: The Stories of Twenty American Kid Inventors* (Farrar Straus & Giroux, New York, 1995).
- [2] Bill Burcham, "Cleared for Landing," *Air & Space*, 20-21 (April/May 1995).
- [3] Joe Conley, Interview, NASA Ames Center, June 19, 1998.